3.23 MTI Clutter Suppression Validation

Summary of Results

Two validation tests for this functional element are included in this document. The first test was conducted for ALARM 3.0, while the second was made using ALARM 3.1. The changes to the MTI FE for ALARM 3.1 were in the calculation of the average gain of the MTI system, for non-block staggered PRF MTIs (i.e., those systems with three or more PRFs and two or less delays). Both sets of validation tests documented here were conducted for MTI radars with two or less PRFs. Therefore, the testing results for ALARM 3.0 are applicable to ALARM 3.1 as well.

Icon Glass MTI Characterization Tests: The comparison of measured MTI response relative to the ALARM modeled MTI response indicates significant differences in the gain/ attenuation at target blind speeds which occur when the relative velocity of the target creates doppler frequencies that are integer multiples of the radar PRF. However, the overall impact of these differences on the prediction of maximum target detection is insignificant.

MTI Response Comparisons: Responses from four MTI modes were tested. The maximum value of the absolute mean difference between measured and modeled MTI responses was approximately 1.2 dB, which corresponds to an approximate detection range difference of 5%. The peaks and nulls of the responses appear to be correctly placed as a function of Doppler frequency with relatively minor amplitude differences overall. The measured single PRF responses appear to be more narrow in the vicinity of zero Doppler than the modeled responses. The perfect modeled responses in ALARM 3.1 would exhibit infinite nulls at zero Doppler frequency if they were not limited by user-supplied inputs to more appropriate values. The fact that the actual MTI system is not perfect and exhibits this limitation in a natural fashion indicates that the measured responses must in fact be more narrow in the zero Doppler frequency region. Based on the observed comparisons between measured and modeled MTI responses, the MTI functional element in ALARM 3.1 appears to be functioning properly at least for single and double delay cancellers.

Functional Element Description

MTI is generally configured as one or more delay-line cancelers which are connected in series. The ideal single delay-line canceler operates as follows. A received pulse signal, delayed by one pulse repetition interval, is compared with the next incoming received pulse signal. If the signal return is from a stationary target, such as clutter, the signals cancel, while if the signals are reflected from a moving target, the signals are coherently integrated, leaving a residue which is the sum of the two target-reflected signals. The delay-line canceler can be considered as a comb filter having the following response:

$$G(f) = \left(2\sin\left(\frac{\pi f_d}{PRF}\right)\right)^{2n} \qquad (3.23\text{-}1)$$

where f_d = doppler frequency of the return
PRF = pulse repetition frequency of the radar
n = number of cancelers

As can be noted from the above response function, at doppler frequencies which are multiples of the PRF, the signal attenuation is a maximum. This results in doppler blind speeds which occur when the relative aircraft velocity is such that the doppler frequency is a multiple of the PRF. At these aircraft velocities the target signal is severely attenuated by the MTI filter and the target may not be detected.

In order to decrease the impact of doppler blind speeds upon target detection, the pulse repetition frequency is staggered, generally at each signal integration interval, such that the blind speed changes for each PRF interval. PRF staggering results in a somewhat different MTI filter response. The MTI response function of a single delay-line canceler for a staggered PRF pair is expressed as:

$$G(f) = 2 - \cos\left(\frac{2\pi f_d}{PRF_1}\right) - \cos\left(\frac{2\pi f_d}{PRF_2}\right) \qquad (3.23\text{-}2)$$

where f_d = doppler frequency of the return
PRF_i = staggered pulse repetition frequencies

The ALARM model uses the above functions to represent the MTI filter. The noise and clutter signals are assumed to have Gaussian frequency distributions such that the clutter and noise signals output from the MTI filter are calculated as the integrated signal level over the response of the MTI filter. The target signal is assumed to be a single spectral line. Therefore, the target signal output from the MTI filter is simply the product of signal input times the amplitude response of the MTI filter at the signal doppler frequency.

The above equations for the response of MTI delay-line cancelers result in infinite attenuation of signal doppler frequencies occurring at multiples of the pulse repetition frequencies. In real radars, because of imperfect implementation and pulse-to-pulse clutter signal amplitude fluctuations, there is a remaining clutter signal residue after clutter signal cancellation, resulting in a finite attenuation of the clutter signal.

3.23.1 ICON GLASS MTI Characterization Tests

Validation Objective : The objective of the validation test is to compare the measured amplitude/frequency response of a specific MTI filter with the ALARM modeled response and determine the impact of any differences between the responses on overall model operation.

Measures of Effectiveness: At the function level, a difference between measured and modeled MTI filter gain of greater than 3.0 dB, observed at any frequency, is considered to exceed acceptable limits. At the model level, a 5% difference in normalized mean target detection range, as predicted by ALARM using modeled and measured MTI response, is considered to be beyond acceptable boundaries.

Test Description: The frequency/amplitude response of a PRF-staggered MTI canceler was measured as part of the ICON GLASS radar characterization test. The specific procedure for measuring the MTI response function consisted of injecting a synthesized, staggered PRF, RF target signal with variable (0.0 Hz to 50.0 kHz) doppler frequency inserted at the antenna feed horn and phase locked to the injected transmitter sample. Video voltage was sampled from a cathode follower amplifier immediately following the MTI delay-line canceler.

Data Description: The test data consisted of measured video voltage, captured at a cathode follower immediately following the MTI delay-line canceler. The pulse voltage was measured at each 200 Hz frequency increment over a doppler frequency range of 0.0 Hz to 50.0 kHz.

Data Processing: Since the input and output voltages of the MTI filter were not directly measured, it was not possible to determine the absolute gain of the MTI delay-line canceler. However, by normalizing to the peak output voltage, it was possible to determine the relative voltage response at each sample doppler frequency. To convert to a frequency/amplitude power response, required for direct comparison with the ALARM modeled response, the measured normalized voltage was then squared and adjusted to correlate with the peak amplitude response of the ALARM modeled MTI peak amplitude response.

Analysis Procedures: The procedure for comparing the measured MTI function response with ALARM modeled response was to simply normalize and convert the measured voltage response to a power response and plot both the measured and modeled MTI response curves for direct comparison. To assess the impact of differences in the measured and modeled MTI function, ALARM was modified to use either the measured or modeled response function. ALARM was then run in Contour Plot mode to determine the difference in target detection range as a function of the MTI response.

Results and Interpretation: Figure 3.23-1 shows plots of both the measured and modeled amplitude response of the MTI filter. As can be observed, the frequencies at which minimum and maximum gain occur for the measured response correlate well with the modeled MTI response. Although there is a maximum gain difference of about 1.0 dB at frequencies where peak gains occur, the gain differences at some null points exceed 5.0 dB, and at 0.0 Hz doppler shift the gain difference exceeds 15.0 dB. This exceeds the suggested acceptance boundary for the function level. Differences in modeled and measured MTI response can be anticipated in that the actual implementation of the delay-line canceler is imperfect. In actual systems, precise pulse-to-pulse frequency correlation or time interval correlation is not possible, resulting in less than ideal pulse integration and cancellation.

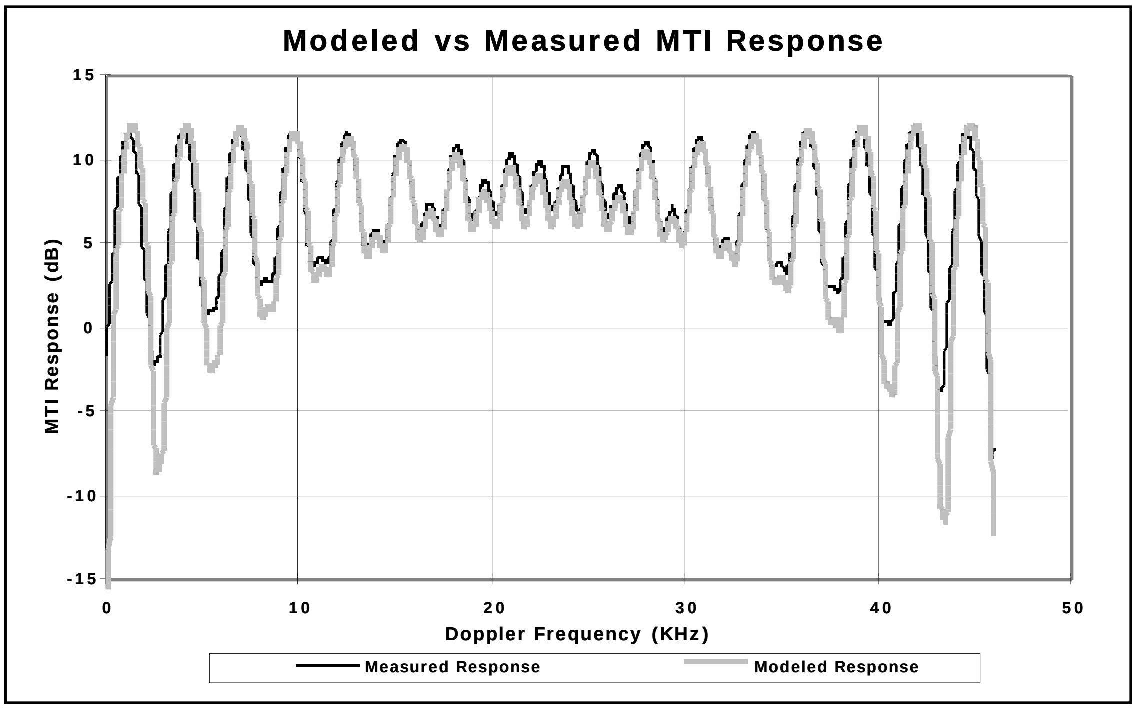

Figure 3.23-1 MTI Response as a Function of Doppler Frequency

Figure 3.23-2 is a plot of ALARM predicted maximum target detection range for offset target flight profiles as a function of measured and modeled MTI response. It is apparent that the differences between measured and modeled MTI response impact target detection. However, the mean normalized difference in target detection is 3.11% as shown in table 3.23-1, well within the suggested validation boundary limits.

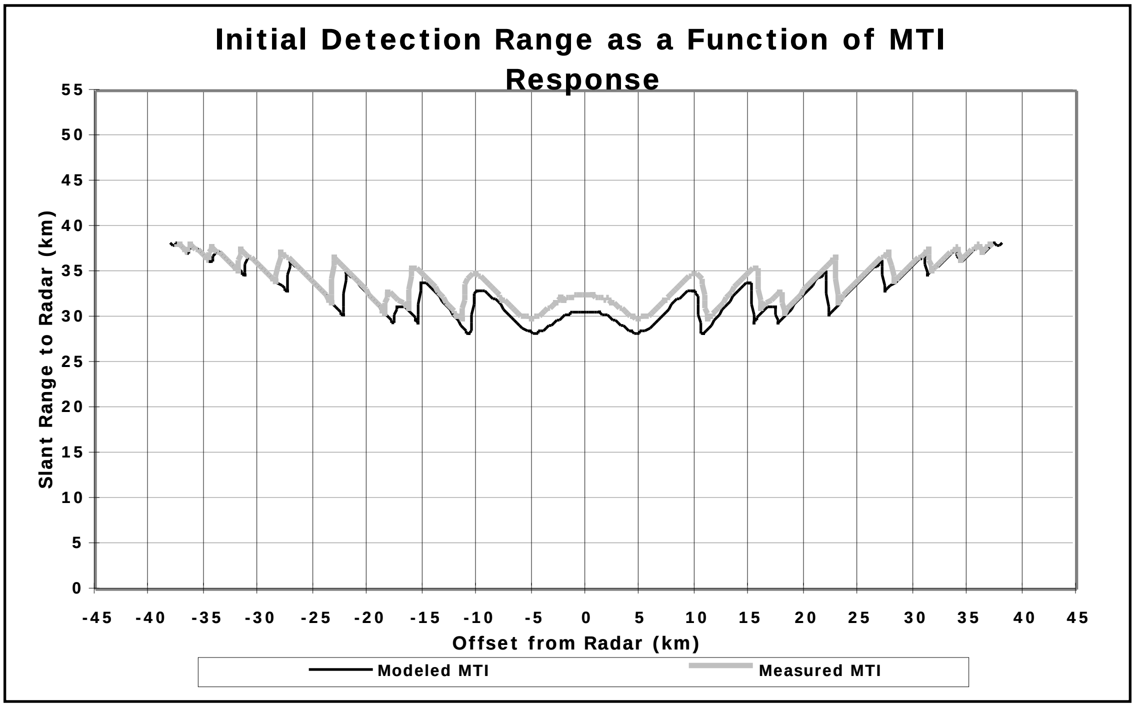

Figure 3.23-2 Initial Detection Range as a Function of MTI Response

Table 3.23-1 Statistics, Target Detection Range as a Function of MTI Response

MTI Response	Mean (m)	σ (m)	Normalized Mean Difference	% Change
Measured	33.73	2.33	-	-
Modeled	32.71	2.81	0.02	3.11

Conclusions: The comparison of measured MTI response relative to the ALARM modeled MTI response indicates significant differences in the gain/attenuation at target blind speeds which occur when the relative velocity of the target creates doppler frequencies that are integer multiples of the radar PRF. This is attributed to the imperfect implementation of real systems such that perfectly coherent integration and cancellation is not practically achievable. This can affect the prediction of both target signal and clutter signal amplitudes. However, the overall impact of these differences on the prediction of maximum target detection is insignificant, within the acceptance boundaries established for functional element validity. The differences between the maximum attenuation of modeled versus real MTI systems can be partially accounted for in ALARM through the use of input parameter FMTIDB, which limits the maximum attenuation of the MTI filter to a user selected value.

3.23.2 MTI Response Comparisons

Validation Objective: Compare the MTI responses generated by ALARM 3.1 with measured MTI responses of the test radar. MTI response comparisons are made with (1) a single PRF with a single canceller, (2) a single PRF with a double canceller, (3) two staggered PRFs with a single canceller, and (4) two staggered PRFs with a double canceller.

Measures of Effectiveness: Differences of approximately 1.7 dB or less between measured and modeled MTI responses will be used to indicate acceptable performance of the MTI functional element. A difference of 1.7 dB in the MTI response corresponds to approximately a 10% difference in target detection range.

Test Description: The MTI responses for four operating modes of the test radar were measured prior to conducting clutter suppression and target detection threshold tests on the test radar.

Data Description: The test data consisted of the measured MTI responses for four operating modes of the test radar.

Data Processing: The measured MTI responses collected at the test facility and analyzed by SIMSUM, Inc., were provided in four ASCII text files. The responses were in units of millivolts. ALARM 3.1 generates MTI responses in terms of power. The measured MTI responses were converted to power responses by the following equation:

$$P = 10 \log\left[\frac{(10^{-3}V)^2}{2}\right] + 30 \tag{3.23-3}$$

where P is power in milliwatts and V is voltage in millivolts.

Four additional ASCII text files with MTI responses converted to the appropriate units were then used to compare with ALARM 3.1 modeled MTI responses.

Analysis Procedures: To generate modeled MTI responses to compare with measured MTI responses, the MTI subroutine RESMTI was removed from ALARM 3.1 and a driver program was written to generate model responses for (1) a single PRF with a single canceller, (2) a single PRF with a double canceller, (3) two staggered PRFs with a single canceller, and (4) two staggered PRFs with a double canceller. The differences (in dB) between modeled and measured MTI responses were then compared.

Results and Interpretation: Figure 3.23-3 shows the measured and modeled MTI responses for the test radar operating with a single pulse repetition frequency and an MTI system with a single canceller. At the Doppler frequencies of $\pm$100 Hz, the difference between measured and modeled MTI responses is approximately 0.5 dB, with the differences decreasing to zero dB at Doppler frequencies of approximately $\pm$27 Hz. For Doppler frequencies between -27 Hz and 27 Hz the difference reaches a maximum of 5 dB at Doppler frequencies of $\pm$5 Hz. The absolute mean difference is approximately 0.5 dB, which corresponds to a range difference in target detection of approximately 3%. The 90 percentile value of the mean difference is approximately 0.8 dB, which corresponds to a range difference in target detection of approximately 5%. The 95 percentile value of the mean difference is approximately 1.5 dB which corresponds to a range difference of approximately 9%.

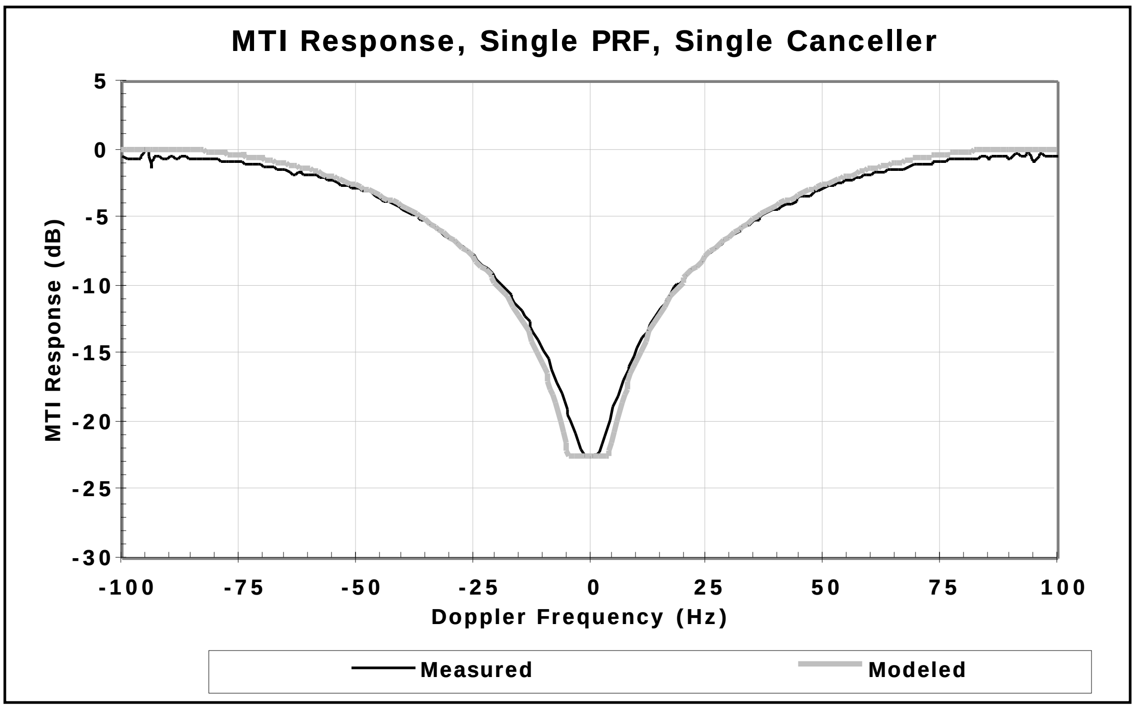

Figure 3.23-3 MTI Responses, Single PRF, Single Canceller

Figure 3.23-4 shows the measured and modeled MTI responses for the test radar operating with a single pulse repetition frequency and an MTI system with a double canceller. At the Doppler frequencies of $\pm$100 Hz, the difference between measured and modeled MTI responses is approximately 1.5 dB, with the differences decreasing to zero dB at Doppler frequencies of approximately $\pm$55 Hz. For Doppler frequencies between -55 Hz and 55 Hz the difference reaches a maximum of 5 dB at Doppler frequencies of $\pm$10 Hz. The absolute mean difference is approximately 1.2 dB, which corresponds to a range difference in target detection of approximately 7%. The 90 percentile value of the mean difference is approximately 2.3 dB which corresponds to a range difference in target detection of approximately 14%. The 95 percentile value of the mean difference is approximately 3.4 dB which corresponds to a range difference of approximately 21%.

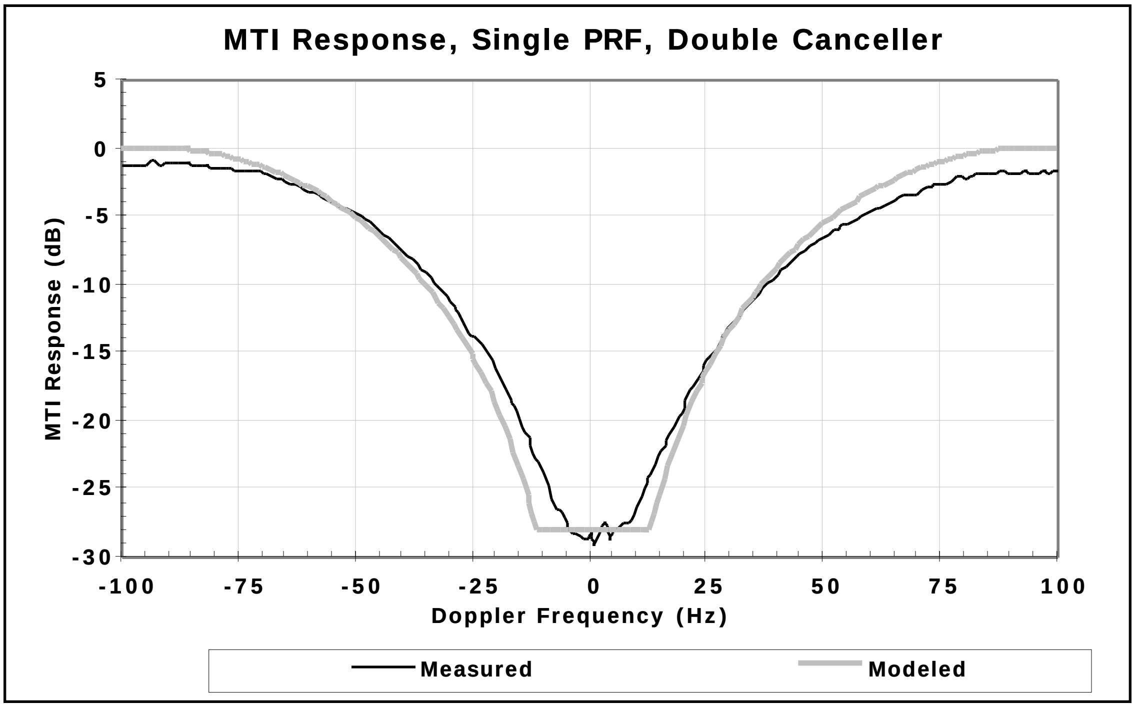

Figure 3.23-4 MTI Response, Single PRF, Double Canceller

Figure 3.23-5 shows the measured and modeled MTI responses for the test radar operating with two staggered pulse repetition frequencies and an MTI system with a single canceller. The absolute mean difference is approximately 1.2 dB, which corresponds to a range difference in target detection of approximately 5%. The 90 percentile value of the mean difference is approximately 1.6 dB which corresponds to a range difference in target detection of approximately 9%. The 95 percentile value of the mean difference is approximately 1.8 dB which corresponds to a range difference of approximately 11%.

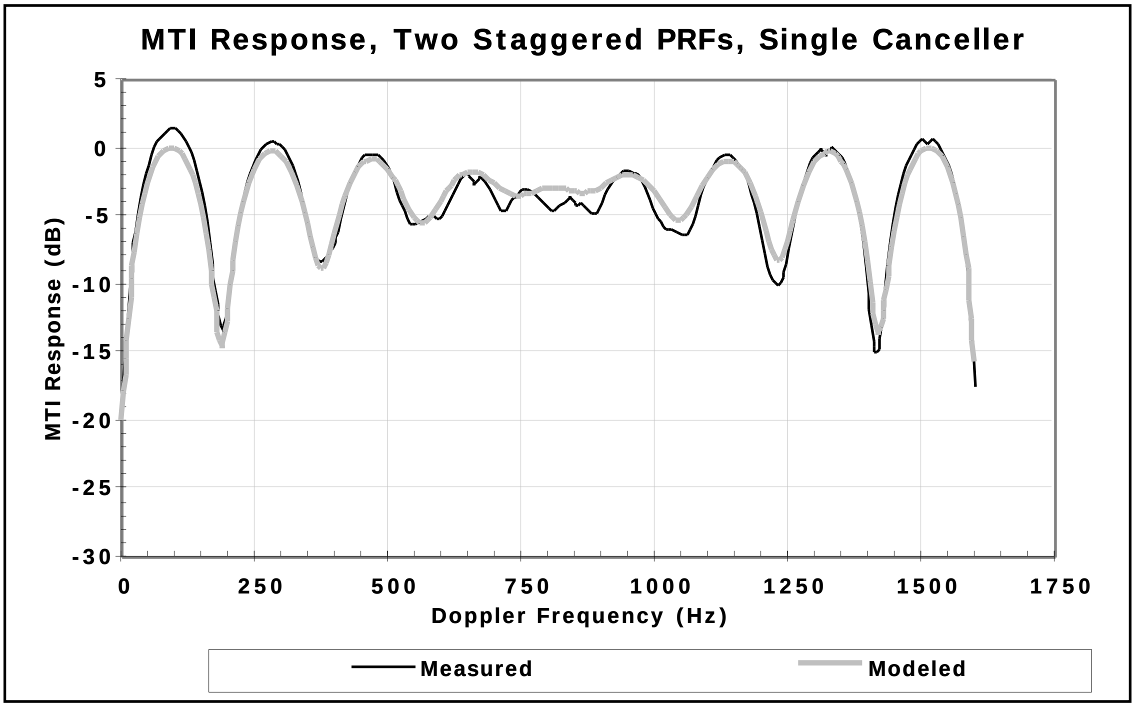

Figure 3.23-5 MTI Response, Two Staggered PRFs, Single Canceller

Figure 3.23-6 shows the measured and modeled MTI responses for the test radar operating with two staggered pulse repetition frequencies and an MTI system with a double canceller. The absolute mean difference is approximately 0.6 dB with corresponds to a range difference in target detection of approximately 3%. The 90 percentile value of the mean difference is approximately 1.4 dB which corresponds to a range difference in target detection of approximately 9%. The 95 percentile value of the mean difference is approximately 2.0 dB which corresponds to a range difference of approximately 12%.

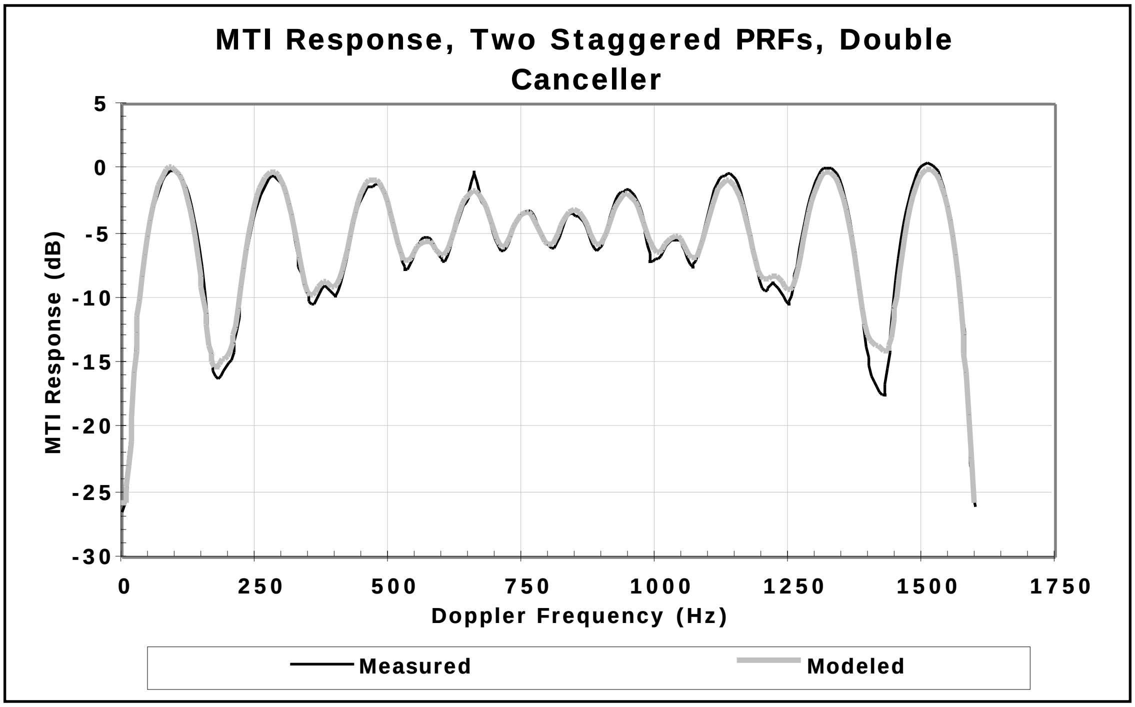

Figure 3.23-6 MTI Response, Two Staggered PRFs, Double Canceller

Conclusions: For the four MTI responses given, the maximum value of the absolute mean difference between measured and modeled MTI responses is approximately 1.2 dB, which is less than the 1.7 dB value which was rather arbitrarily set for a measure of effectiveness. A difference of 1.2 dB corresponds to an approximate detection range difference of 5%. The maximum value of the 90 percentile mean difference is 2.3 dB which occurred for the single PRF and an MTI system with a double canceller. All other responses were less than approximately 1.6 dB which again is less than the 1.7 dB value set for a measure of effectiveness. An examination of the four MTI response figures indicates that the peaks and nulls of the responses appear to be correctly placed as a function of Doppler frequency with relatively minor amplitude differences overall. The measured single PRF responses appear to be more narrow in the vicinity of zero Doppler than the modeled responses. The perfect modeled responses in ALARM 3.1 would exhibit infinite nulls at zero Doppler frequency if they were not limited by user supplied inputs to more appropriate values. The fact that the actual MTI system is not perfect and exhibits this limitation in a natural fashion indicates that the measured responses must in fact be more narrow in the zero Doppler frequency region. Based on the observed comparisons between measured and modeled MTI responses, the MTI functional element in ALARM 3.1 appears to be functioning properly at least for single and double delay cancellers.